HSRL-2 observations of aerosol variability during an aerosol build-up event in Houston and comparisons with WRF-Chem

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High Spectral Resolution Lidar 2 —
• measures profiles of aerosol optical properties at 3 wavelengths
• Flew on DAQ California, Houston, and Colorado
HSRL-2 measurement products

September 11, 2013

Mixed layer heights inferred from backscatter

Extensive variables

Intensive variables

Aerosol classification uses intensive variables to infer aerosol type

3 angstrom exponents

2 lidar ratios

Aerosol Backscatter 355, 532, 1064 nm

Aerosol Extinction 355, 532 nm

Aerosol Depolarization 355, 532, 1064 nm

Lidar Ratio (532 nm)
WRF-Chem model run performed by Pablo Saide, U. Iowa, for the SEAC4RS campaign, to provide guidance for flight planning and evaluate model in near-real time.

Domain includes the DISCOVER-AQ Houston campaign as well.

- WRF-Chem v3.5 CBMZ, 4bin MOSAIC, 12km dx, 52 vertical lvls, and WRF-tracer for emission regions/sectors.
- Emissions: anthropogenic, biomass burning (FINN, QFED2) with plume-rise, MEGAN biogenics, dust & sea-salt. MACC boundary conditions.
- AOD assimilation (NRL product) every 3 hours, 1 cycle a day (Saide et al., ACP 2013)
Day by day extinction comparison
Extinction comparison, lidar vs. model

Sept 11 AM

Sept 11 PM
Extinction comparison, lidar vs. model

Sept 12 AM

Sept 12 PM

Altitude (km)

HSRL-2
Extinction (532 nm)

WRF-Chem
Extinction (532 nm)

1
0.56
0.32
0.18
0.1
0.056
0.032
0.018
0.01
0.0056
0.0032
0.0018
0
1
0.56
0.32
0.18
0.1
0.056
0.032
0.018
0.01
0.0056
0.0032
0.0018
0
Extinction comparison, lidar vs. model

Sept 13 AM

Sept 13 PM

HSRL-2
Extinction (532 nm)

WRF-Chem
Extinction (532 nm)
Insights about aerosol source & type
Aerosol source and type, 6 example layers

Sept 11 AM
- smoke
- anthropogenic

Sept 11 PM
- pure aged wildfire smoke

Sept 12 AM
- agricultural smoke + anthropogenic mix
- pure smoke

Sept 13 AM
- smoke-rich mix
Anthropogenic vs. Smoke
A vs. C
Anthropogenic vs. Smoke: A vs. C

see Burton et al. 2012, AMT, for HSRL aerosol typing

HSRL-2 provisional aerosol classification for DAQ-Houston

- smoke
- anthropogenic
CO Fire along back-trajectory

Sept 11 PM

WRF-Chem Backtrajectories

HSRL2 EXT
MODEL EXT
MODEL CO FIRE
MODEL CO ANTHRO
Mixtures of Agriculture Smoke and Anthropogenic D vs. F
Mixtures of Agriculture Smoke and Anthropogenic: D vs. F

agricultural smoke + anthropogenic mix

Sept 12 AM

Sept 13 AM

smoke-rich mix
Sept 12 AM, residual layer

CO Fire along back-trajectory

HSRL2 EXT

MODEL EXT

MODEL CO FIRE

MODEL CO ANTHRO
see Duncan, B. N., et al. *Atmos Environ*, 2014
HSRL-2 Intensive Properties

Sept 12 AM

agricultural smoke + anthropogenic mix

Sept 13 AM

smoke-rich mix

Lidar ratio, 532 nm

Color ratio, 355/532 nm

Lidar ratio, 532 nm

Color ratio, 355/532 nm

Smith Point 14:27 - 14:43

Deer Park 16:03 - 16:20
Effect of Relative Humidity on lidar intensive properties: setup and assumptions

- Diameter-independent growth factor:
  \[ D_{amb} = g \times D_{dry} \]
  the entire size distribution simply shifts to larger diameters as the particles grows.

- Correction is applied to both real and imaginary parts of refractive index following:
  \[ m_{amb} = \frac{m_{dry} + m_{H2O}(g^3 - 1)}{g^3} \]

  \[ g = \left( 1 + \kappa \frac{RH}{100\% - RH} \right)^{\frac{1}{3}} \]
  where \( \kappa \) is the effective hygroscopicity parameter which captures all solute properties.

Less hygroscopic \( \Leftarrow \) 0 \( \leq \kappa \leq 1 \) \( \rightarrow \) More hygroscopic

Continental aerosols: \( \kappa = 0.27 \pm 0.21 \)  
Clean marine aerosols: \( \kappa = 0.72 \pm 0.24 \)  
Agricultural smoke: \( \kappa = 0.2 \)  
(Pringle et al., 2010, ACP)  
(Rose et al., 2010, ACP)
Lidar intensive properties: effect of Relative Humidity

\[ \kappa = 0.1 \]
\[ \kappa = 0.3 \]

\[ r_{\text{eff}} = 0.11\text{um}, \; mR = 1.45, \; ml = 0.005 \]
\[ r_{\text{eff}} = 0.16\text{um}, \; mR = 1.51, \; ml = 0.01 \]
Pure Smoke
B,C,E
Pure Smoke: B,C,E

- Sept 11 AM: Smoke
- Sept 11 PM: Pure aged wildfire smoke
- Sept 12 AM: Pure smoke
Lidar intensive properties for 6 aerosol samples

• Lidar intensive variables vary both within and between types
• Extinction angstrom exponent varies monotonically with size but is noisy
• Lidar ratio related to absorption, but also varies with particle size, as much as angstrom exponent does
• Backscatter color ratios have complicated dependence on size and complex refractive index

Variations within a type due to
• mixing
• humidification
• composition differences due to different sources (for smoke: e.g. wildfire vs. agricultural)
• aging & processing, etc.
• ???
Summary

• HSRL-2 makes horizontally and vertically resolved observations of aerosol layering and diurnal and day-to-day evolution
• High information content in HSRL-2 observations provides the opportunity for model assessment
• HSRL-2 measures a large set of intensive parameters that give information on aerosol type
• Subtleties in HSRL-2 intensive parameters have the potential to give a more nuanced understanding of aerosols
• WRF-Chem model gives context on aerosol sources and transport that helps with interpretation of lidar data
• DISCOVER-AQ Houston case study
  o characterized by large variability in aerosol properties, vertically, temporally and in observed optical properties.
  o included local anthropogenic pollution plus relatively fresh agricultural smoke and aged transported wildfire smoke
EXTRA: WHAT DOES IN SITU SAY?
B: UH Moody Tower, 20130911, 14.84-15.07
C: Smith Point, 20130911, 19.75-19.97
D: Smith Point, 20130912, 14.45-14.71
E: West Houston, 20130912, 15.14-15.43
F: Deer Park, 20130913, 16.05-16.33
DISCUSSION OF VARIABILITY OF INTENSIVE PARAMETERS OF SMOKE
Effective radius

Single Scattering Albedo (532nm)

Total number concentration